Mass wasting in planetary environments: Implications for seismicity

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Overview

On Earth, mass wasting events such as rock falls and landslides are well known consequences of seismic activity. Here we investigate the regional effects of seismicity in planetary environments with the goal of determining whether such surface features on the Moon, Mars, and Mercury could be triggered by fault motion (Fig. 1).

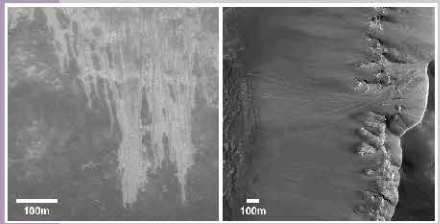
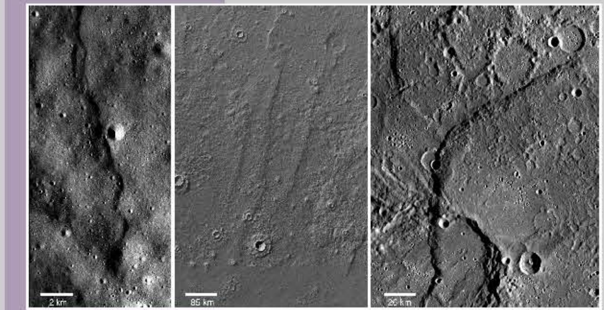


Fig. 1: (left) Landslide deposits (granular flow) on an interior slope of Marius crater on the Moon (11.9°N, 50.8°E).

(right) Boulder tracks emanating from a crater rim alcove on Mars (9.515°N, 16.433°E). A 74 km compressional fault in the Arabia Sabaea Terra is located <100km away.

Fig. 2: Examples of lobate scarps



Moon	Mars	Mercury
Evershed S1 center lat/lon 33°N/197.1°E	Utopia Planitia #s 1801, 1802, 1804 center lat/lon 52.9°N/119.2°E	Beagle Rupes center lat/lon 3.5°N/100.7°E

Lobate scarps

Lobate scarps, the typical surface expressions of thrust faults resulting from tectonic compression, are widely observed on the Moon, Mars, and Mercury (Figs. 2&3). Compared to other types of faults, surface-cutting thrust faults require the largest amount of stress to form and/or slip, so they could possibly generate large quakes. While normal faults, graben, and wrinkle ridges may be more abundant on Mars, the Moon, and Mercury respectively, these structures would create smaller theoretical maximum quakes than lobate scarp thrust faults. Thus, we optimize our chances of finding mass wasting associated with faults by studying lobate scarps.

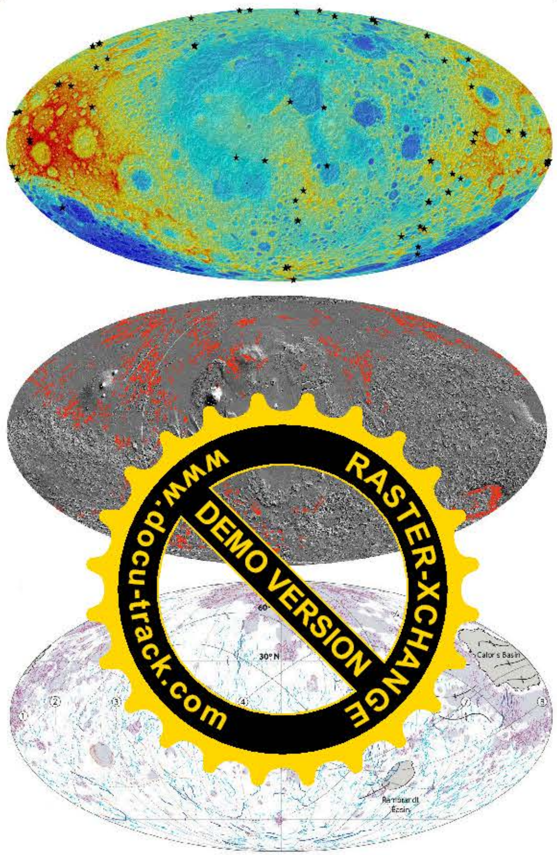
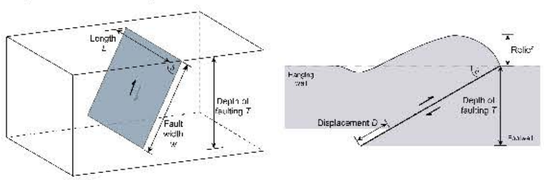


Fig. 3: (top) Lunar lobate scarps [1]. (middle) Young compressional faults on Mars [2]. (bottom) Thrust fault related tectonic features on Mercury (blue = cratered plains, pink = smooth plains). [3]

Fig. 4: Theoretical maximum quake

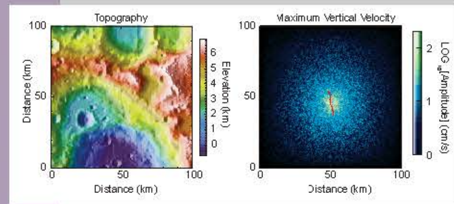


We derive the theoretical maximum quake magnitude a given scarp can produce from basic fault properties. These are either estimated from imagery or derived from laboratory rock experiments or elastic dislocation models, and include the length (L), dip angle (δ), depth of faulting (T), displacement (D), and fault width (w) (Fig. 4).

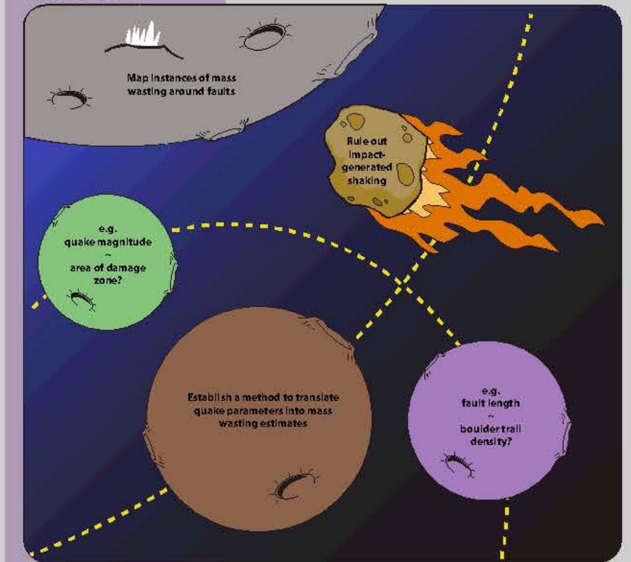
Wavefield modeling

To determine the dimensions of an area affected by seismic shaking, we model the ground motion resulting from the theoretical maximum quake along a given fault (Fig. 5). We use a numerical code for simulating seismic wave propagation through arbitrary elastic and anelastic media in a 3-D model space (including topography). Peak vertical ground motion typically occurs within a few kilometers of the main shock and drops off rapidly from there. This implies that we should expect most of the mass wasting phenomena to occur in the immediate vicinity of the fault. However, this result may depend on regional effects like surface slope and megaregolith thickness. A thicker megaregolith (as might be expected in the vicinity of craters) would tend to focus shaking in some of the crater basins. Sediments can also enhance seismic shaking; this could be a relevant scenario for Martian craters that may have been lakes at some time in the past.

Fig. 4: (left) LOLA surface topography input into the wave propagation simulation. The Evershed scarp is centered in the image (see Fig. 2). (right) Predicted maximum vertical ground motion for a $M_w=7.8$ quake on a subjacent reverse fault with a 2.25 km depth of faulting. The surface trace of the scarp is marked with a red line. A random distribution of heterogeneity of 25% in S and P wave velocity with 100 km scale length scatterers is placed in the megaregolith to simulate the scattering observed on Apollo seismograms.



Future work



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[3] Byrne, P. K.; Klimczak, C.; Şengör, A. M. C.; Solomon, S. C.; Watters, T. R.; Hauck, S. A. (2014) Mercury's global contraction much greater than earlier estimates. Nature Geoscience 7, 301–307.